"ROVs in a Bucket"
Contagious, Experiential Learning by Building Inexpensive, Underwater Robots

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***Abstract*- A Remotely Operated Vehicle (ROV) can be an underwater robot. A simple ROV has been developed that can be built by grade-school children using off-the-shelf and off-the-Internet parts. PVC pipe is used for the frame, bilge pump motors for thrust, and speaker wire transfers power and control information from the switch box to the robot. Soldering is not required. Once constructed, these ROVs are safely powered by 12v car batteries and are small enough to be run inside a 30 gallon trash can or small pool. Parts for the ROV kit can be purchased for under $125 (sans camera and lights). A detailed ROV build manual is available from doug.levin@noaa.gov. The program is an effective delivery tool that links marine science with a host of other, related disciplines.**

I. Introduction

The Marine Industry seeks recruiting assistance [1]. Dr. Robert Ballard of The Institute for Exploration says students not engaged in science by the 8th grade will not choose that path [2]. The shortage of youth "in the pipeline" is blamed on a lack of experiential programs that launch contagious interest in the sciences [3]. The Ocean Exploration edict identifies education and outreach as important components to entice students into the field [4].

"ROVs in a Bucket" integrates Marine Technologies into classrooms in a contagious, effective manner that may help. This program was developed through a NASA/Academic partnership, and grew through training with the Marine Advanced Technology Education Center (MATE) of Monterey Peninsula College. Student groups introduced to ROVs with this program have gone on to compete internationally in the MATE ROV competition.

Using ROVs as a platform for learning encourages interdisciplinary/cross-curricular instruction. Its use strongly supports parallel development of Ocean Literacy and the introduction of marine related career paths [5]. Subjects such as science, math, physics, technology, art, and history are delivered without students knowing it. Techniques for critical thinking, team building, sportsmanship, verbal and written communication skills are all delivered with this program. Lessons can address specific topics or entire units. The program is hands-on and demonstrates value-added topics, such as, basic tool use, electrical concepts, buoyancy, and propulsion.

A simple underwater robot kit has been developed so an ROV can be designed, built and operated by grade-school children in less than an hour. All parts are readily available from local hardware stores, hobby stores, or by searching the Internet. A parts list for the ROV shown in Fig. 1 is included as an appendix at the end of this paper.

PVC pipe is used for the frame, bilge pump motors for thrust, and speaker wire transfers the power and control information from switches to the robot. The ROVs are best deployed in a pool. Fig. 1 shows a basic ROV design that roughly measures 60cm X 30cm X 40cm with a 10m tether. The PVC holds together with pressure and friction. Glue is not necessary. The larger buoyancy tubes are held to the frame with plastic cable ties. The pieces can be quickly disassembled and reassembled to test optimum ROV designs. Soldering is not needed. These ROVs are safely powered by a 12v battery that does not pose an electrical hazard when used near a pool. They can be built small enough to run inside a 30 gallon trash can or a small wading pool. The cost for each system kit is under $125. When a small ($150) lipstick camera is attached, underwater viewing is facilitated on small, inexpensive TVs. (This requires 110v near a pool and safety considerations).

II. The Program

Effective program delivery requires the use of a pool (indoor or outdoor) and some open space whether it is a clean lawn or a concrete patio base. Local YMCA's have been great resources that have volunteered their facilities or charged nominally for their use. Safety issues involving electrical devices in the pool area are alleviated by explaining the innocuous nature of the 12v battery systems employed. Issues may arise with the need for electricity to transmit underwater video to poolside monitors. Safety considerations, in this case, should allow ample distance from the water to the viewing systems. The thrusters are pre-wired to a controller containing three double pole, double throw (dpdt) switches. Each switch controls one of the thrusters. The thrusters are arranged such that two are aligned horizontally and pointed to the front of the ROV. These control the horizontal

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movement, front and back, and allows for turns in the horizontal plane. The third thruster is aligned vertically and serves to propel the ROV down or up, depending on the mission requirements. The tether that connects the controller to the thrusters is nominally 10m long. This allows for plenty of freedom of movement in a pool setting. The thrusters are connected to a PVC piece that is easily integrated into whatever PVC frame system the students devise. The controller system and buckets of PVC parts are laid out in the program area so that students can see what is "coming" and then are able to access the parts when the time to build comes.

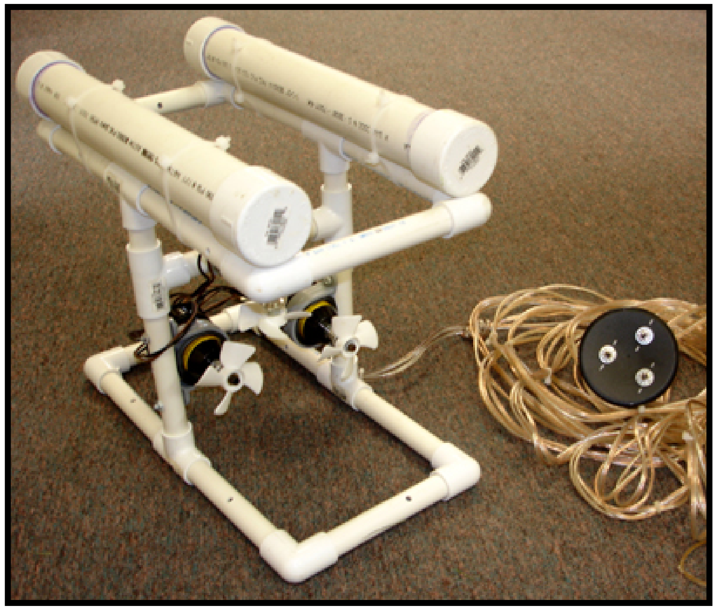

Fig. 1 The Program ROV, 10m Tether, and controller

The time for a typical three hour program is distributed as follows:

Intro to ROVs	20 minutes
How to build an ROV – Instruction	20 minutes
Design and Build ROV	60 minutes
Regional & National Competition Overview	10 minutes
Test ROVs in pool , troubleshoot, and mini competition	60 minutes
Wrap up, Clean up, and Evaluations	10 minutes

The "Intro to ROVs" is more than a cursory introduction to the mechanical attributes of an underwater robot. It includes links to possible career paths (in NOAA), how ROVs are used in the Oil Industry, and how Sanctuaries may use them to assist with habitat mapping, among others.

During the "How to Build" Instructional Session, workshop attendees are introduced to a small, professionally built and commercially available ROV (Video Ray) (Fig.2). They are verbally quizzed to elicit design requirements from the attendees, as opposed to being subjected to dry lecture (pardon the pun); "What is the function of the frame? How many motors are required to make it go forward and back, left and right, up and down? What mission do you want the ROV to accomplish? What tools do you need? Define buoyancy and ballast." During the pool-side program Video Ray is available for students to operate. Following this introduction, the students are broken up into groups. Groups of three have been found to be most effective in collaborative learning activities [5]. The groups are shown to buckets containing parts to build an ROV. The PVC parts used to construct the frame fit tightly when joined through elbow and "T" fittings and do not require glue to stay together. Specific lessons related to the ROV that are touched on during this session may include the following, as an example:

The Frame: The frame of an ROV has two purposes, structure and protection. It holds all of the thrusters and tools that the ROV might employ to complete a mission, and the wire connections that bring the information from the surface to the ROV. During operations ROVs might encounter tight spaces. If the "working" parts are connected inside the frame, then the frame takes the brunt of the force and the ROV will continue to work after bouncing off of the side and bottom of the pool.

Propulsion: With three strategically placed motors the ROV can move in any direction (Fig.3). Two motors are installed facing the front of the ROV, one on the port side and the other on the starboard side. If both are powered in the same direction at the same time the ROV will move forward. If the polarity of the motors is reversed, the ROV will move backwards. To make the ROV turn left, the starboard motor is pushed forward, and the port motor reversed. The asymmetry of the motor movement causes the ROV to turn left. If a right turn is needed, the left motor will be pushed forward and the starboard motor back. The up and down movement is effected by a motor that is positioned vertically on the ROV frame. With the ROV slightly positively buoyant, when power is applied in the "down" direction, this thruster will cause the ROV to dive. When power to this thruster is placed in the "up" position, the ROV will return to the surface (with the aid of buoyancy).

Fig 2 Video Ray used at workshops by participants

The participants are then given a sixty minute period to design and build an ROV. Groups determine their ROV design and then visit the buckets to collect the PVC pieces they project are necessary to build their design. This might involve a number of elbows, T's, and straight pieces to which the thruster assembly is integrated. During this time, the facilitators roam the program area giving design tips, but do not make corrections. It's a good learning moment for the groups to discover the problems on their own. At the end of this 60 minute period the ROVs are built, tested and ready to launch into the pool.

At this point in time, when, for example, NOAA is sponsoring the workshop, the groups take a break and a short session is interjected where the "captive audience" is introduced to the Sanctuary Program. This may also be an opportunity to showcase the local host facility to those in attendance i.e. Nauticus, a maritime themed science center in Nofolk, VA (www.nauticus.org) where workshops are now being held fairly regularly.

Finally, the groups are allotted sixty minutes to test and adjust their ROV design and partake in a mini-competition that emulates events their students may encounter at the regional competitions. During the testing period the groups launch their ROVs and see how their designs fair. It's also the time where mechanical and electrical functionality of the ROV are evaluated.

Fig 3 three thrusters give the ROV mobility forward, back, left, right, up & down

Common problems encountered during this phase of the program include discovery of poor ergonomic design that affects the Pilot's ability to control the ROV. For example, prior to installing the ROV thrusters into the frame the group should test and mark which switch controls which thruster. There are three switches arranged in a triangle on the controller (Fig 4). Ideally, the bottom two switches control the horizontal thrusters; the left drives the "port" thruster and the right drives the starboard. The switch at the apex (topmost of the three switches seen in Fig 4) controls the vertical thruster. This pattern allows the pilot to think logically while driving the ROV through its paces.

Problems arise when the thrusters are installed in the ROV frame without testing which switch controls which thruster. If the thrusters are installed in the ROV frame without testing the "top" switch may end up controlling the port or starboard thruster and the left, or right switch the vertical thruster. This will likely lead to confusion of the pilot and reduces the confidence that the ROV will be steered correctly to meet mission specific directives. If the controller wiring is found to be incorrect, the unglued PVC frame pieces allow the ROV to be pulled apart, the thrusters placed in the correct configuration, and re-launched within minutes. Other common design flaws are discovered as soon as the ROV is lowered into the pool where it may sink or float, list to one side or the other, or pitch to the bow or stern. This problem is easily solved by strategic placement of foam for buoyancy or lead fishing weights. Sometimes additional plastic cable ties are needed to add rigidity to the frame or secure the buoyancy pontoons to the frame more tightly.

The next part of the program pits the different groups against each other in a mini-ROV competition. This may involve a race "out and back" to a specific line in the pool. This mainly tests the skill of the pilot and tether management team to keep the ROV on a straight path. Other tests may include retrieval of something on the pool bottom or, perhaps, a tug-of-war between opposing ROVs. The competition is devised to show participants the need for teamwork and clear communication to complete a task efficiently.

The final session of the workshop allows the leaders to recap the experience and lets participants reflect on what they've learned. It's important to afford those in attendance the opportunity to provide anonymous, written, feedback that may be used to improve future workshops. A compilation of six sets of workshop evaluations and a cursory analysis of those is offered later in this paper.

III. Audience

A range of audiences have been introduced to "ROVs in a Bucket" through formal and informal education programs involving a diverse demographic and range of ages down to thirteen years (Fig 5, 6 7). In addition to presenting this through formal grade school (8 -12) programs, it has been effectively delivered informally, to pre-service teachers (undergraduates), certified school teachers, and executives seeking to improve team-skills in the workplace. Recently the program was introduced to a troubled inner-city school system. They subsequently participated in the 2nd annual Mid-Atlantic MATE ROV competition.

Fig 4 The Controller Switch Arrangement.

IV. Workshop Evaluation Results

Over the past two years ten "ROV in a bucket" workshops have been held at various venues throughout the Eastern United States. Participants included environmental trainers, ROV users, student teachers, pre-service teachers, and certified secondary educators. Anonymous evaluations were collected from six of the workshops and tabulated. Tables 1, 2 and 3 summarize and report responses of the participants as harvested from the workshop evaluations. Each of the participants attended the workshop on their own accord, voluntarily, and without compensation. Attendance was solicited by personal invitation, direct mailing or they chose the workshop among selections offered at a conference. Some of the comments reflect the quality of the workshop design and delivery more than the subject content. These are included to aid future workshop designers to consider "intangible" program components that make participants more receptive to the content.

The number following the description of the program piece being evaluated represents the "n" or number of the respondents that filled out the evaluation form. The next number is the percentage that replied as better than "very good", where the spectrum of choice from poor to excellent was as follows: value of the ranking scale ranged from 0 to 6; as follows:

Not Applicable (or "no" in a yes/no question)
Poor
Fair
Average
Good
Very Good
Excellent (or "yes" in a yes/no question)

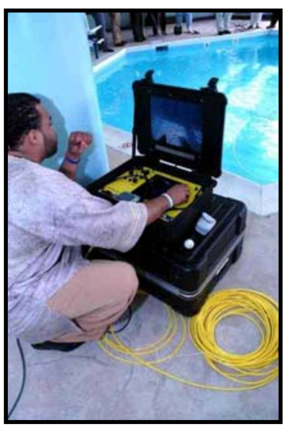

Fig 5 Operating VideoRay

Fig 6 Building an ROV

Fig 7 Launching ROVs

TABLE 1: Responses to NOAA Workshop Evaluations. N is the number of respondents, and the % is the percentage of the N that responded favorably as very good or excellent.

Program Piece Being Evaluated	**N**	**%>Very Good**
Workshop addressed advertised topics	60	98
Workshop was well led, organized, and interactive	60	100
Prior Information was prepared, provided, and helpful	60	92
Participants are likely to implement workshop & tools	60	70
Participants appreciated the introduction to Sanctuaries*	56	97
Participants appreciated the introduction to Nauticus*	10	60
Participants had enough time to build the ROV	49	100
The Quality of Instruction	69	97
Likelihood that participants will enter national or international competitions	87	86
The Overall Workshop Effectiveness	54	100
Would Student Attendance Enhance the Experience?	35	74

TABLE 2: Tally of responses to interest in other workshop topics. N is the number of respondents, and the % is the percentage of the N that indicated a strong interest in the topic.

Workshop Interest	**N**	**% of N Interested**
Weekend Workshops	27	100
Weekday Workshops	27	37
Teacher at Sea Opportunities	27	67
Faculty/Mentor Matchmaking	27	56
Web Site Sharing	27	48
Internship Possibilities	27	67
Training/Support Workshops	27	74
Curriculum Development	27	22

"Other" Comments written on the evaluations were as follows:

Had "little knowledge of ROVs before attending".
Enjoyed the email explaining the workshop/directions/procedures before hand.
Would have appreciated additional/more information (prior to the workshop)
Particularly appreciated the detailed email with workshop logistics sent a week in advance.

Good Information for any robotics class.
Awesome (2)
Many of the principles will be of use.
Appreciate the hard work
Already set aside time to use ROVs as a team building exercise.

Lots of fun – hands-on learning (8)
Would like information as to how to get students interested.
Can't wait to incorporate this into the curriculum.
There should have been an instructional session on how to build your ROV.
More discussion on how to integrate ROVs into the curriculum
This activity would be great for a Marine Biology class.
Would like more instruction on integrating buoyancy, motors, propulsion, etc. and connecting these processes with science.

In one instance, unbeknownst to the workshop conveners, an experienced ROV user attended the workshop. The comment from this individual supported the thought that teachers may welcome assistance integrating real world experience into the classroom. *"The experiential aspect was by far the most exciting and helpful. As an ROV user I've never considered how one is built so this was a superb opportunity to consider things from a different perspective."*

TABLE 3: Evaluations collected during the 2007 NASA Pre Service Teacher Conference. 25 participants responded to the anonymous survey.

Which of the following best describes the workshop	% in Agreement
Lecture	0
Hands-On	100
Interactive Discussion	0
How Engaged Were the Participants	
Totally Engaged	100
Somewhat Engaged	0
Somewhat Bored	0
Completely Bored	0
What skills/concepts did the workshop address	
Collaboration	100
Cutting edge technology	100
Classroom Management	74
Sophisticated use of technology	100
New math/science concepts	100
Enthusiasm for teaching	100
NASA resources	50
Online resources	80
What was (were) the best thing about the workshop	
	Extremely Interactive (7 comments)
	Building the ROVs (4 comments)
	Trainer was completely engaging
	Excellent hands-on session
	Problem Solving
What was (were) the worst thing about the workshop	Couldn't keep the ROVs

IV. Results & Conclusion – Workshop Effectiveness

Hands-on learning is more effective than wrote learning [6] [7]. When the lessons are transferred using methods that allow students to tangibly see the connections they are more likely to retain the information. In addition, teachers are better able to transfer new knowledge that is learned in intimate, experiential settings [8].

The quality of the workshop is measured by several things. In this case, the subject matter is the "draw". Marine Science has been "popularized" by media by showcasing the likes of Jacques Cousteau and Bob Ballard. There is a lot of mystique and draw to programs that romanticize shipwrecks, pirates, and the search of lost treasure. Recognizing this connection, an undergraduate course that melded the technology of underwater search and salvage with business acumen proved to be a popular offering at a Business Specialty College [9]. Another factor that drew the participants to the workshop was that it was "hands-on". Other, unmeasured draws might include the reputation of the institution offering the program and/or that of the workshop leaders. As the workshop programs are repeated, over time, its reputation offered through testimonials or "word of mouth" may encourage others to sign up.

The effectiveness of the program is reflected in the number of evaluations that rated various aspects of the workshop at very-good or above (excellent). A tally of 60 evaluations over a half-a-dozen workshops shows a high level of satisfaction in both the materials presented and how it was delivered. All participants left with a sense of accomplishment and a high level of confidence that they could effectively transfer the new knowledge to their own classrooms.

Expected lessons learned at the workshop included designing an ROV so that it meets mission specific objectives, mechanical design, concepts of buoyancy and propulsion and electricity. Many of the respondents reflected great satisfaction that the program transcended ROV design. Virtually 100% of the workshop attendees indicated that the workshop was very worthwhile. Skills and concepts that were highly rated included collaboration, introduction to cutting edge/sophisticated technology, classroom management, and innovative ways to introduce new math/science concepts. All participants were totally engaged in the program and expressed a need for more of these types of programs that deliver multiple, complex concepts through hands-on activities. The experiential learning techniques create ownership and lasting impressions of the "lessons learned".

V. Acknowledgment

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VII. Appendix

Parts List for ROV in Fig 1

14	6" pieces of ½" Schedule 40 PVC	2	3" pieces of ½" Schedule 40 PVC
8	90 degree elbows ½" Schedule 40 PVC	6	T's ½" Schedule 40 PVC
2	15" pieces of 1 ½" Schedule 40 PVC	4	1 ½" end caps Schedule 40 PVC
3	600 GPM Bilge Pump Cartridges	3	Master Airscrew Direct Drive Prop Adapter Kits
3	Plastic Muffin Fan Blades	3	30' lengths of 18 gauge speaker wire
1	10' length of 18 gauge speaker wire	1	16 oz clear plastic container w/ plastic screw on lid
1	½" male adapter Schedule 40 PVC	1	½" conduit locknut
3	dpdt 3 amp switches center off (moment) on-off-on	18	Molex wire connectors for AWG 22-18 wire
9	4" lengths of 18 gauge red wire	6	4" lengths of 18 gauge green wire
3	4" lengths of 18 gauge black wire	2	Ring Crimp Terminals – red & black for 18 gauge wire
3	1 ½" Plastic Conduit Clamps	6	1 ¼" machine screws with nuts and washers
3	30" lengths of Temflex Rubber Tape	1	100 pack of 4" plastic tie wraps
1	20" length of black electrical tape	4	14" plastic tie wraps
2	Wire Nuts – Ideal #30-072	1	3/16" shrink wrap (I get one black, one yellow)
1	3/32" shrink wrap (I get one green, red, and black)	1	Silver Permanent Sharpie Marker

Tools List

Hack Saw or Circular Saw to cut PVC pieces	Power Drill
Drill bits – 3/8" wood bit, 13/16" wood bit	Wire cutter (diagonals)
Wire stripper/crimper	Heat Gun
Allen wrench (2) one for prop adapter set screw and one for hub	Tape Measure
12" Ruler	Permanent magic marker – fine-tip ("Sharpie")

ROV Operations

Power: The ROV operates on 12v DC power. It is suggested that operators use an emergency jump start device for power.
Cameras: www.helmetcamera.com. The submersible helmet camera (lipstick camera) sells for $169.00.
TV Monitor: A small 13" TV can be purchased used for under $50.00.
Lights: Waterproof Pelican Mitylite (www.forestry-suppliers.com).
Storage: Controller assemblies survive transportation when contained in a Sterelite 10Qt Container 1844-White.
Transportation: Plastic 5 gallon buckets - hence ROVs in a Bucket
Detailed Build Manual: "ROVs in a Bucket" instructional booklet is available from doug.levin@noaa.gov